

## Accelerator probes for new stable quarks

K. M. Belostky<sup>1</sup>, M. Yu. Khlopov<sup>1,2,3</sup>, K. I. Shibaev<sup>1</sup>

<sup>1</sup>*National Research Nuclear University "Moscow Engineering Physics Institute", 115409 Moscow, Russia*

<sup>2</sup>*Centre for Cosmoparticle Physics "Cosmion" 115409 Moscow, Russia*

<sup>3</sup>*APC laboratory 10, rue Alice Domon et Léonie Duquet  
75205 Paris Cedex 13, France*

### Abstract

The nonbaryonic dark matter of the Universe can consist of new stable double charged particles  $O^{--}$ , bound with primordial helium in heavy neutral O-helium (OHe)"atoms" by ordinary Coulomb interaction. O-helium dark atoms can play the role of specific nuclear interacting dark matter and provide solution for the puzzles of dark matter searches. The successful development of composite dark matter scenarios appeals to experimental search for the charged constituents of dark atoms. If  $O^{--}$  is a "heavy quark cluster"  $\bar{U}\bar{U}\bar{U}$ , its production at accelerators is virtually impossible and the strategy of heavy quark search is reduced to search for heavy stable hadrons, containing only single heavy quark (or antiquark). Estimates of production cross section of such particles at LHC are presented and the experimental signatures for new stable quarks are outlined.

## 1 Introduction

The cosmological dark matter can consist of dark atoms, in which new stable charged particles are bound by ordinary Coulomb interaction (See [1, 2, 3] for review and references). In order to avoid anomalous isotopes overproduction, stable particles with charge -1 (and corresponding antiparticles), as tera-particles [4], should be absent [5], so that stable negatively charged particles should have charge -2 only.

Such stable double charged particles can hardly find place in SUSY models, but there exist several alternative elementary particle frames, in which heavy stable -2 charged species,  $O^{--}$ , are predicted:

- (a) AC-leptons, predicted in the extension of standard model, based on the approach of almost-commutative geometry [6, 7, 8, 9].
- (b) Technileptons and anti-technibaryons in the framework of walking technicolor models (WTC) [10, 11].
- (c) and, finally, stable "heavy quark clusters"  $\bar{U}\bar{U}\bar{U}$  formed by anti- $U$  quark of 4th [6, 12, 13, 14] or 5th [15] generation.

All these models also predict corresponding +2 charge particles. If these positively charged particles remain free in the early Universe, they can recombine with ordinary electrons in anomalous helium, which is strongly constrained in the terrestrial matter. Therefore cosmological scenario should provide a mechanism, which suppresses anomalous helium. There are two possibilities, requiring two different mechanisms of such suppression:

- (i) The abundance of anomalous helium in the Galaxy may be significant, but in the terrestrial matter there exists a recombination mechanism suppressing this abundance below experimental upper limits [6, 8].
- (ii) Free positively charged particles are already suppressed in the early Universe and the abundance of anomalous helium in the Galaxy is negligible [3, 13].

These two possibilities correspond to two different cosmological scenarios of dark atoms. The first one is realized in the scenario with AC leptons, forming neutral AC atoms [8]. The second assumes charge asymmetric case with the excess of  $O^{--}$ , which form atom-like states with primordial helium [3, 13].

If new stable species belong to non-trivial representations of electroweak SU(2) group, sphaleron transitions at high temperatures can provide the relationship between baryon asymmetry and excess of -2 charge stable species, as it was demonstrated in the case of WTC [10, 16, 17, 18].

After it is formed in the Standard Big Bang Nucleosynthesis (SBBN),  ${}^4\text{He}$  screens the  $O^{--}$  charged particles in composite ( ${}^4\text{He}^{++}O^{--}$ ) *O-helium* “atoms” [13].

In all the proposed forms of O-helium,  $O^{--}$  behaves either as lepton or as specific “heavy quark cluster” with strongly suppressed hadronic interaction. Therefore O-helium interaction with matter is determined by nuclear interaction of  $\text{He}$ . These neutral primordial nuclear interacting objects contribute to the modern dark matter density and play the role of a nontrivial form of strongly interacting dark matter [19, 20].

The cosmological scenario of O-helium Universe allows to explain many results of experimental searches for dark matter [3]. Such scenario is insensitive to the properties of  $O^{--}$ , since the main features of OHe dark atoms are determined by their nuclear interacting helium shell. It challenges direct experimental search for the stable charged particles at accelerators and such search strongly depends on the nature of  $O^{--}$ .

Stable -2 charge states ( $O^{--}$ ) can be elementary like AC-leptons or technileptons, or look like elementary as technibaryons. The latter, composed of techniquarks, reveal their structure at much higher energy scale and should be produced at LHC as elementary species. They can also be

composite like "heavy quark clusters"  $\bar{U}\bar{U}\bar{U}$  formed by anti- $U$  quark in one of the models of fourth generation [12, 13] or  $\bar{u}_5\bar{u}_5\bar{u}_5$  of (anti)quarks  $\bar{u}_5$  of stable 5th family in the approach [15].

In the context of composite dark matter scenario accelerator search for stable particles acquires the meaning of critical test for existence of charged constituents of cosmological dark matter.

The signature for AC leptons and techniparticles is unique and distinctive what allows to separate them from other hypothetical exotic particles. In particular, the ATLAS detector has an unique potential to identify these particles and measure their masses.

Test for composite  $O^{--}$  can be only indirect: through the search for heavy hadrons, composed of single  $U$  or  $\bar{U}$  and light quarks (similar to R-hadrons). Here we study a possibility for experimental probe of this hypothesis.

## 2 New stable generations

Modern precision data on the parameters of the Standard model do not exclude [21] the existence of the 4th generation of quarks and leptons.

In one of the approaches the 4th generation follows from heterotic string phenomenology and its difference from the three known light generations can be explained by a new conserved charge, possessed only by its quarks and leptons [12, 13, 14, 22]. Strict conservation of this charge makes the lightest particle of 4th family (neutrino) absolutely stable, but it was shown in [22] that this neutrino cannot be the dominant form of the dark matter. The same conservation law requires the lightest quark to be long living [12, 13]. In principle the lifetime of  $U$  can exceed the age of the Universe, if  $m_U < m_D$  [12, 13].

In the current implementation of the "spin-charge-family-theory" [15] there are predicted two sets with four generations each, so that the 4th generation is unstable, while the lightest (5th generation) of the heavy set has no mixing with light families and thus is stable. If  $m_{u_5} < m_{d_5}$  and their mass difference is significant, OHe dark matter cosmological scenario can be realized in this theory. For the lower possible mass scale ( $\sim 1TeV$ ) for the 5th generation particles, their search at LHC is possible along the same line as for stable particles of 4th generation in the approach [12, 13, 14, 22]. In the successive discussion we'll consider stable  $u$ -type quark without discrimination of the cases of 4th and 5th generation, denoting the stable quark by  $U$ .

Due to their Coulomb-like QCD attraction ( $\propto \alpha_c^2 \cdot m_U$ , where  $\alpha_c$  is the QCD constant) stable double and triple  $U$  bound states ( $UUq$ ), ( $UUU$ )

can exist [12, 4, 5, 13, 14, 15]. The corresponding antiparticles can be formed by heavy antiquark  $\bar{U}$ . Formation of these double and triple states at accelerators and in cosmic rays is strongly suppressed by phase space constraints, but they can be formed in early Universe and strongly influence cosmological evolution of 4th generation hadrons. As shown in [13], anti-U-triple state called anutium or  $\Delta_{3\bar{U}}^{--}$  is of a special interest. This stable anti- $\Delta$ -isobar, composed of  $\bar{U}$  antiquarks can be bound with  ${}^4He$  in atom-like state of O-helium [6].

Since simultaneous production of three  $U\bar{U}$  pairs and their conversion in two doubly charged quark clusters  $UUU$  is suppressed, the only possibility to test the models of composite dark matter from 4th (or 5th) generation in the collider experiments is a search for production of stable hadrons containing single  $U$  or  $\bar{U}$ .  $U$ -quark can form lightest ( $Uud$ ) baryon and ( $U\bar{u}$ ) meson with light quarks and antiquarks.  $\bar{U}$  can form the corresponding stable antiparticles, like  $\bar{U}\bar{u}\bar{d}$  and  $\bar{U}u$ . Search for these stable hadrons is similar to the R-hadrons search. The main task will be to distinguish R-hadrons from hadrons, containing quarks of 4th or 5th generation. R-hadrons will be accompanied by supersymmetric particles, what is not the case for 4th or 5th generation hadrons.

### 3 Signatures for $U$ -hadrons in accelerator experiments

In spite of that the mass of  $U$ -quarks can be quite close to that of  $t$ -quark, strategy of their search should be completely different.  $U$ -quark in framework of the considered models is stable and will form stable hadrons at accelerator contrary to  $t$ -quark.

Detailed analysis of possibility of  $U$ -quark search requires quite deep understanding of physics of interaction between (meta-)stable U-hadrons and nucleons of matter. However, methodic for  $U$ -quark search can be described in general, if we know mass spectrum of  $U$ -hadrons and (differential) cross sections of their production. Cross section of  $U$ -quark production in pp-collisions is presented on the Fig. 1. For comparison, cross sections of 4th generation leptons are shown too. Cross sections have been calculated with program CompHEP [23]. Cross sections of  $U$ - and  $D$ - quarks virtually do not differ. For quarks ( $U$  and  $D$ ) the obtained values were re-scaled in correspondence of estimations done with program Hathor [24]. Heavy stable quarks will be produced with high transverse momentum  $p_T$  and velocity, which is less than speed of light. In general, simultaneous measurement of velocity and momentum provides us information about mass of particle. Information on ionization losses are, as a rule, not so good. All

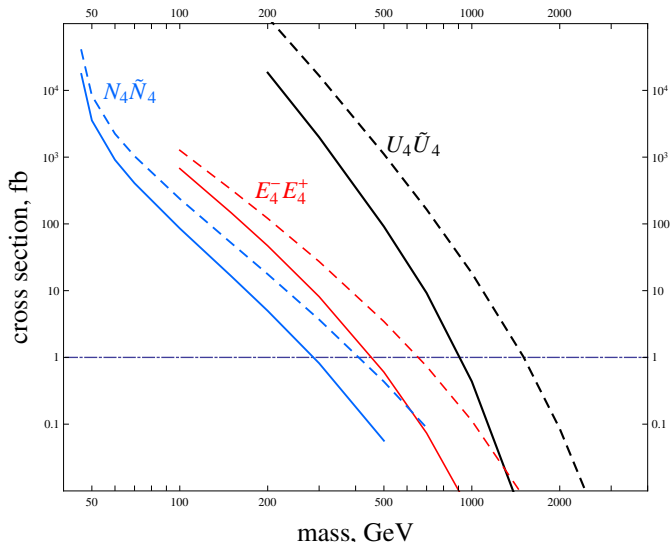


Figure 1: Cross sections of production of 4th generation particles (N, E, U (D)) at LHC. Solid and dashed curves correspond to c.m. energies 7 and 14 TeV respectively. Horizontal dashed line shows approximate level of sensitivity to be reached in 2012 (at the energy 7 TeV).

these features are typical for any heavy particle, while there can be subtle differences in the shapes of their angle- and  $p_T$ -distribution, defined by concrete model, which it predicts. It is the peculiarity of long-lived hadronic nature what can be of special importance for clean selection of events of  $U$ -quarks production.

$U$ -quark can form a whole class of  $U$ -hadron states which can be considered as stable in the conditions of an accelerator experiment contrary to their relics in Universe. But in any case, as we pointed out, double and triple  $U$ -hadronic states cannot be virtually created at collider. Many other hadronic states, whose lifetime exceeds  $\sim 10^{-7}$  s, should also look as stable in accelerator experiment. In the Table 1 expected mass spectrum of  $U$ -hadrons, obtained with the help of code PYTHIA [25], is presented.

The lower indexes in notation of  $U$ -hadrons in the Table 1 denote the nonzero spin  $s = 1$  of the pair of light quarks. From comparison of masses of different  $U$ -hadrons it follows that all  $s = 1$   $U$ -hadrons decay quickly emitting  $\pi$ -meson or  $\gamma$ -quantum, except for  $(Uss)$ -state. In the right column the expected relative yields are presented. Unstable  $s = 1$   $U$ -hadrons decay onto respective  $s = 0$  states, increasing their yields.

There are two mesonic states being quasi-degenerated in mass:  $U\bar{u}$  and

Table 1: Mass spectrum and relative yields in LHC for U-hadrons

	Difference of masses of U-hadron and U-quark, GeV	Expected yields in % (in the right columns the yields of long-lived states are given)	
$\{U\tilde{u}\}^0, \{U\tilde{d}\}^+$	0,330	39,5(3)%, 39,7(3)%	
$\{U\tilde{s}\}^+$	0,500	11,6(2)%	
$\{Uud\}^+$	0,579	5,3(1)%	7,7(1)%
$\{Uuu\}_1^{++}, \{Uud\}_1^+, \{Udd\}_1^0$	0,771	0,76(4)%, 0,86(5)%, 0,79(4)%	
$\{Usu\}^+, \{U\bar{s}d\}^0$	0,805	0,65(4)%, 0,65(4)%	1,51(6)%
$\{Usu\}_1^+, \{U\bar{s}d\}_1^0$	0,930	0,09(2)%, 0,12(2)%	
$\{Uss\}_1^0$	1,098	0,005(4)%	

$U\bar{d}$  (we skip here discussion of strange  $U$ -hadrons). Interaction with the medium composed of  $u$  and  $d$  quarks transforms  $U$ -hadrons into those ones containing  $u$  and  $d$  (as it is the case in the early Universe [12, 13, 14]). The created pair of  $U\bar{U}$  quarks will fly out of the vertex of pp-collision as  $U$ -hadrons with positive charge in 60% of all  $U$ -quark events and as neutrals in 40% (correspondingly, 60% with negative charge and 40% neutrals for  $\bar{U}$  hadrons). After traveling through the matter of detectors, at a distance of a few nuclear lengths from vertex,  $U$ -hadrons will transform in (roughly) 100% of positively charged hadrons ( $Uud$ ), while  $\bar{U}$ -hadrons will convert in 50% into negatively charged  $\bar{U}$ -hadron ( $\bar{U}d$ ) and in 50% to neutral  $\bar{U}$ -hadron ( $\bar{U}u$ ).

This feature will enable to discriminate the considered case of  $U$ -quarks from variety of alternative models, predicting new heavy stable particles.

Note that if the mass of Higgs boson exceeds  $2m$ , its decay channel into the pair of stable  $Q\bar{Q}$  will dominate over the  $t\bar{t}$ ,  $2W$ ,  $2Z$  and invisible channel to neutrino pair of 4th generation [26]. It may be important for the strategy of heavy Higgs searches.

## 4 Conclusions

The cosmological dark matter can be formed by stable heavy double charged particles bound in neutral OHe dark atoms with primordial He nuclei by

ordinary Coulomb interaction. This scenario sheds new light on the nature of dark matter and offers nontrivial solution for the puzzles of direct dark matter searches. It can be realized in the model of stable 4th generation or in the approach unifying spin and charges and challenges for experimental probe at accelerators. In the context of this scenario search for new heavy stable quarks acquires the meaning of direct experimental probe for charged constituents of dark atoms of dark matter.

The  $O^{--}$  constituents of OHe in the model of stable 4th generation and in the "*spin-charge-family-theory*" are "heavy quark clusters"  $\bar{U}\bar{U}\bar{U}$ . Production of such clusters (and their antiparticles) at accelerators is virtually impossible. Therefore experimental test of the hypothesis of stable  $U$  quark is reduced to the search for stable or metastable  $U$  hadrons, containing only single heavy quark or antiquark. The first year of operation at the future 14 TeV energy of the LHC has good discovery potential for  $U(D)$ -quarks with mass up to 1.5 TeV, while the level of sensitivity expected in the 2012 at the LHC energy 7 TeV can approach to the mass of 1 TeV.  $U$ -hadrons born at accelerator will distinguish oneself by high  $p_T$ , low velocity, by effect of a charge flipping during their propagation through the detectors. All these features enable to strongly increase the efficiency of event selection from not only background but also from alternative hypothesis. In particular, we show that the detection of positively charged  $U$ -baryon in coincidence with  $\bar{U}$ -mesons (50% neutrals and 50% negatively charged) provides a distinct signature for the stable  $U$  quark. Analysis of other channels of new particles production provides distinctions from the case of R-hadrons. In the latter case all the set of supersymmetric particles should be produced.

It should be noted that the "*spin-charge-family-theory*" predicts together with stable 5th generation also 4th generation of quarks and leptons, which are mixed with the three known families and thus unstable. Experimental probe for new unstable heavy particles implies definite prediction for their mass spectrum and branching ratios for their modes of decay.

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